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(54) Title of the Invention: Single Frequency Oscillation Laser Device

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Specifications

1. Title of the Patent: Single Frequency Oscillation Laser Device

2. Scope of the Patent's Claims

A single frequency oscillation laser device, characterized by the fact that it is provided with a main laser unit including a laser substance enabling simultaneous laser oscillations with a plurality of spectral lines, a resonator comprising a partially reflecting mirror and a total reflection mirror, arranged opposite parallel reflecting surfaces in this laser medium, and a restricting aperture which restricts in the vicinity of the central axis of the resonator the effective sectional area of the reflecting mirror forming the construction of the resonator;

forming a Fabry-Pérot interferometer with a construction enabling hermetic sealing of a gas between two reflecting mirrors, wherein two reflecting mirrors, mounted in parallel opposite each other, are inserted in said resonator;

wherein the laser oscillations which are conducted simultaneously with said laser medium display a higher absorption with one of the spectral lines in a plurality of spectral lines enabling oscillations than the absorption achieved with the wavelength of other spectral lines;

and the resonance frequency of said resonator existing within the gain curve of one of said spectral lines is formed with the construction of a Fabry-Pérot interferometer comprising a sealed-in gas which is regulated by the sealing pressure so as to include the transmission frequency band of the a Fabry-Pérot interferometer.

3. Detailed Explanation of the Invention

This invention relates to a device designed as a laser device having a laser substance enabling simultaneous laser oscillations with a plurality of spectral lines.

Laser oscillations can be generally conducted in many modes and in some cases, simultaneous oscillations can be conducted with many wavelengths using a laser property. For instance when carbon dioxide laser gas (hereinafter called CO_2 laser) and molecules of similar infrared lasers are used, simultaneous oscillations can be conducted with several spectral lines branched into P, Q, and R.

It is generally important to have a laser oscillating at a single wavelength with a power source that is suitable for a tracking system and a distance measuring device using the telodyne wave detection technology applied to light rays. To enable the use of such devices, relatively compact designs have been developed in recent years which are suitable for a CO_2 laser with excitation in the horizontal direction, sealed under atmospheric pressure (hereinafter called TEA CO_2 laser), enabling to obtain a large output. The following is a detailed explanation of this invention based on the TEA CO_2 laser.

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Figure 1 shows a representative example of the construction of a TEA CO_2 laser. As shown in the figure, (1) is a total reflection mirror, (2) is a resonator in the form of a partially reflecting mirror having a reflectance approximately in the range of 80 ~ 90% operating as an output mirror providing output of laser light (3) from the inner part of the resonator. The construction of the resonator consists of total reflection mirror (1) and partially reflecting mirror (2) which are deployed opposite each other in the parallel direction. Number (4) indicates a laser

medium which is excited by discharge excitations with high voltage pulse applied at a high speed, comprised of a mixed gas including carbon dioxide gas (CO_2), nitrogen gas (N_2) and helium gas (He) sealed as a laser medium approximately under atmospheric pressure in which discharge electrodes are deployed orthogonally to optical axis (5).

Although it is possible to conduct simultaneous oscillations with many spectral lines having branches P and R with a width of 10.6 μm when the pressure of the sealed in gas in the CO_2 laser is low, in a high TEA CO_2 laser sealed approximately under atmospheric pressure, the oscillation lines will be suppressed by dependence on pressure depending on the cross-sectional surface area of the induced discharge and on the time period or relaxed rotations. In many cases it is possible to conduct simultaneous rotations with three spectral lines, line P (20) which has a band P (20) of 10.6 μ with the highest gain and peripheral line P (18), as well as line P (22).

Figure 2 explains the situation occurring with this oscillation mode. As shown in Figure 2, curves A, B and C indicate the gain curve of respective lines P (22), P (20) and P (18), D indicates the resonance frequency of the resonator as is, that is to say in the vertical mode, and E indicates the threshold value of oscillations.

When laser oscillations exceed the threshold value in the curve of the gain, oscillations can be conducted with a resonance frequency determined by the resonator (in vertical mode). The situation of the laser oscillation mode in this case is shown in Figure 2. In addition, the frequency gap in the vertical mode will be in inverse proportion to the resonance gap. Due to the spreading of the pressure during the gain curve of a TEA CO_2 laser, the same oscillations will be conducted in several vertical modes with a small length of the resonator in the range of 20 ~ 30 cm. In addition, although this is not shown in the figure, simultaneous oscillation can be also conducted in a high-order horizontal mode (distribution mode in the horizontal direction of the beam profile) with oscillations using different frequencies regardless of the frequency of the vertical mode. While no special control is usually exercised with this design, simultaneous oscillations will be conducted with many modes (many frequencies) with a plurality of spectral lines.

In order to use this TEA CO_2 laser for oscillations with a single frequency, control must be exercised to generate oscillations with a single spectral line, while the horizontal mode is controlled at the same time with the basic mode (to achieve the same frequency as in vertical mode), and the vertical mode must be selected singly.

Figure 3 explains a construction example of a single frequency oscillation device according to prior art. Also in this figures, numbers (2), (4), and (5) indicate the same items as the same numbers in Figure 1. Number (6), which is a diffraction grating used as a wavelength distribution element for selection of a single spectral line, is replaced with a total reflection mirror. Because of that, oscillations can be conducted for example only with spectral line P (20). The wavelength can be selected by applying rotational scanning to diffraction grating (6) to change the incident angle of the laser beams striking grating (6). Number (7) is a scanning mechanism used for this purpose. In addition, selection of the horizontal mode is achieved by

limiting the sectional area of the laser beams entering limiting aperture (8) inside the resonators to the vicinity of the center of the optical axis, increasing the diffraction loss of the high-order mode with the distribution of energy to the peripheral part of the reflecting mirror and suppressing high-order mode oscillations.

Further, a Fabry-Pérot interferometer (9) for a single selection of the vertical mode is inserted in the resonator. The construction of this Fabry-Pérot interferometer (9) consists of 2 reflecting mirrors (10a) and (10b) which are deployed opposite each other in the parallel direction. One of the reflecting mirrors (10a) can be moved in the parallel direction by using for this purpose driving device (11) using an electrostriction element, etc. Furthermore, the reflecting mirrors (10a) and (10b) are deployed vertically to the optical axis (5).

Figure 4 explains the situation during the oscillation mode created with the construction of the oscillator shown in Figure 3.

When the gap between reflecting mirrors (10a) and (10b) is d, the transmittance T of Fabry-Pérot interferometer (9) can be calculated according to the following formula:

$$T(v) = \left(\frac{1-A}{1-R}\right)^2 \frac{1}{1 + [4R/(1-r\}^2\ \}\ \sin^2(2\pi\ v\ nd/c)} \quad \ldots\ldots (1)$$

Wherein v is the number of oscillations of the laser light, R is the reflectance of reflecting mirrors (10a) and (10b), A is the absorption loss occurring when the light has passed once through the medium 1 between reflecting mirror (1) and reflecting mirror (10b), n is the index of refraction of the medium, and c is the speed of light.

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Figures 4 (c) and (d) explain one example of the distribution of the transmission spectrum of this Fabry-Pérot interferometer (9). The distribution in the vicinity of the extreme transmittance value corresponds approximately to Lorentz equation, and the half value width can be expressed with the following formula:

$$\Delta^{v}\infty = \frac{C\ (1 - R)}{2\pi \sqrt{R}\ nd} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

and the interval Δvf between the neighboring extreme value can be expressed with the following formula:

$$\Delta vf = \frac{C}{2^{nd}} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

To achieve a single selection in the vertical mode of the laser, the values R, d, and n of Fabry-Pérot interferometer (9) must be set so that the width of the gain curve of Δvf is increased and the vertical mode interval of Δvm is decreased.

Figure 4 explains the situation when the laser oscillation mode is selected to achieve oscillations with spectral line P (2) through diffraction grating (6). Figure 4 (b) indicates a laser oscillation mode when the vertical mode is selected while the Fabry-Pérot interferometer (9) is not inserted in the resonator, Figure 4 (a) shows oscillations when 5 vertical modes D are run simultaneously in the gain curve B above the threshold value E of the oscillations. Figures 4 (c), (d), and (e) show the situation when the oscillation mode is run while the Fabry-Pérot interferometer (9) is inserted in the resonator. Figure 4 (c) indicates the transmittance distribution of the Fabry-Pérot interferometer (9) when the medium inside the Fabry-Pérot interferometer (9) is gas, $A \fallingdotseq 0$, and $n \fallingdotseq 1$. In addition, Figure 4 (c) also shows all the vertical modes D. Figure 4 (d) shows the situation when gap d between the reflecting mirrors of the Fabry-Pérot interferometer (9) is changed so as to achieve vertical mode D in the vicinity of the extreme value F of transmittance with the scanning frequency. As was explained above, this will increase the oscillation threshold value of vertical modes other than the vertical modes in the vicinity of the extreme value of transmittance so that oscillations will no longer be generated and single mode (single frequency) oscillations will be conducted as shown in Figure 4 (e).

However, the problem with this design was that expensive parts were required according to this prior art method for the diffraction grating, etc., and also a large size of the design was created because a mechanical scanning mechanism was required for the Fabry-Pérot interferometer (9) and for the diffraction grating, resulting in a complicated design.

In order to resolve the above described problems, this invention uses a single spectral line oscillation design wherein a gas displaying absorption characteristics and wavelength selectivity is sealed between two reflecting mirrors of a Fabry-Pérot interferometer using a single vertical mode. In addition, because frequency scanning of the Fabry-Pérot interferometer is used to change the pressure of said sealed in gas, the design enables single oscillations without causing fluctuations of the refractive index. The design will now be explained in details based on the enclosed figures.

Figure 5 shows on embodiment of this invention. Numbers (1), (2), (4), and (5) correspond to the same components that are shown in Figure 1, and numbers (8), (10a) and (10b) correspond to the same components as those shown in Figure 3.

The horizontal mode is selected in the same way by inserting a restricting aperture (8) in the resonator according to a conventional method. Fabry-Pérot interferometer (12) is deployed approximately in the vertical direction to optical axis (5) for a single vertical mode. This Fabry-Pérot interferometer is deployed opposite two reflecting mirrors (10a) and (10b) mounted in the parallel direction to each other. After a gas is introduced into a light transmission window in

these two reflecting mirrors (10a) and (10b), the construction is sealed to create a hermetically sealed construction.

The gas sealed in this construction is a gas having absorptive characteristics. This makes it possible to suppress laser oscillations with an absorption loss received from the gas due to another spectral line that one of the desired spectral lines among a plurality of possible spectral lines of laser oscillation.

The following is an explanation of a case in which a single oscillation is induced with spectral line P (2) whose band is 10.6 μm in a TEA CO_2 laser. The gas used in this case has absorptive characteristics with the wavelength of spectral line P (22) and spectral line P (18) . In addition, although it is ideal if there is no absorption with the wavelength of line P (20), some degree of absorption is possible. The loss caused by the absorption enables oscillations within a range not exceeding the gain of P line (20) and the oscillations thus can be realized without imparting a large loss to line P (20) in a state when oscillations are suppressed when a large absorption loss is received from another line that line P (20), since the gain of line P (20) is the highest when compared to other lines. It can be assumed that dinitrogen monoxide (N_2O) is among the types of gases that can be used for this purpose, enabling to realize the characteristics described above combined with absorbing characteristics.

The absorbing characteristics of the above described sealed in gas can be used for the selection of the wavelength to control oscillations with a single spectral line.

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Figure 6 explains the operation in this case. Similarly to Figure 2 (a), Figure 6 (a) shows gain curves A, B, and C and vertical mode D with P line (18), P line (20) and P line (22) and vertical mode, wherein laser oscillations are enabled in the gain curve above the threshold value in vertical mode. When Fabry-Pérot interferometer (12) is used with the absorbing characteristics of the sealed in gas according to this invention, it is possible to control 1 vertical mode within the gain curve with a single spectral line so as to achieve a value above the threshold value. Figure 6 (b) shows one example of a transmission curve with a frequency in the vicinity of P line (18), P line (20), and P line (22) of the sealed in gas inside Fabry-Pérot interferometer (12). While P line (18) and P line (22) have a strong absorption, laser oscillations generated with P line (20) are characterized by small absorption. In addition, Figure 6 (c) shows one example the transmission spectrum of Fabry-Pérot interferometer (12) containing a gas and vertical mode D.

As one can see from Formula (1) which indicates the transmittance of the Fabry-Pérot interferometer, since the value of A (which indicates the absorption of the medium) in Formula (1) displays the frequency characteristics shown in Figure 6 (b), when the medium of the Fabry-Pérot interferometer is gas ($A \fallingdotseq 0$), unlike in Formula 4 (c), the pinnacle vale of the transmittance of the Fabry-Pérot interferometer in the frequency band displaying an extreme value is increased in gain curve B of P line (20), and decreased in gain curve values C and A of the other lines, line

P (18) and line P (22). Because of that, as shown in Figure 6 (d), the gain oscillation above the threshold value H are created only with transmitting frequency band G of said Fabry-Pérot interferometer in gain curve B of P line (20). Incidentally, in order to induce laser oscillations, frequency scanning of Fabry-Pérot interferometer (12) is required to input the vertical mode frequency in this frequency band G. This scanning, as one can see from Formula (3), can be realized by changing the index of refraction of the gas sealed in the Fabry-Pérot interferometer, which enables regulation of the index of refraction of the sealed in gas by changing the pressure. Therefore, the laser oscillations can be induced with a single frequency within the spectral line of P line (20) as shown in Figure 6 (e).

Although the explanation above pertained to single frequency oscillations of a TEA CO_2 laser, this invention is not limited to this example as it is also possible to use a laser device for simultaneous laser oscillations with multiple spectral lines using krypton ion laser, etc.

As was explained above, the signal frequency oscillation laser device of this invention provides a design for a single oscillation spectral line wherein a gas displaying absorbing characteristics with wavelength frequency selectivity is sealed between two reflecting mirrors of Fabry-Pérot interferometer for single frequency oscillations in the vertical mode. In addition, because the scanning frequency of the Fabry-Pérot interferometer can be used to change the pressure of the above described sealed in gas in order induce single frequency oscillations, expensive parts required for a frequency selection element are no longer required, and also a scanning mechanism thus becomes unnecessary, which makes it possible to achieve in this manner a compact and simplified design of an inexpensive device.

4. Brief Explanation of Figures

Figure 1 shows a construction example of a TEA CO_2 laser, Figure 2 is a diagram explaining the operation of a TEA CO_2 laser indicating the relationship between the gain curve, vertical mode, oscillation threshold value and the frequency of the laser oscillation mode, Figure 3 is a construction diagram of a single frequency laser oscillation diagram according to prior art, Figure 4 is a diagram explaining the operation of a device according to prior art indicating the relationship between the gain curve, vertical mode, threshold value, transmittance of a Fabry-Pérot interferometer and the frequency of the laser oscillation mode, Figure 5 explains one embodiment of this invention, and Figure 6 a diagram explaining the operation of a device according to this invention indicating the relationship between the gain curve, vertical mode, threshold value, transmittance of a Fabry-Pérot interferometer and the frequency of the laser oscillation mode.

In these figures, number (1) indicates a total reflection mirror, (2) is a partially reflecting mirror, (3) is laser light, (4) is a laser medium, (5) indicates optical axis, (6) is diffraction grating, (7) is a scanning mechanism, (8) is a restricting aperture, (9) is a Fabry-Pérot interferometer, (10a) and (10b) are reflecting mirrors, (11) is a driving device, (12) is a Fabry-Pérot interferometer, letters A, B, C indicate a gain curve, D is the resonance frequency of the

resonator (vertical mode), E is the threshold value of oscillations, F is the extreme value of the transmittance of the Fabry-Pérot interferometer, G is the transmitting frequency band of the Fabry-Pérot interferometer, and H is the threshold value of oscillations.

In addition, the same codes are applied to corresponding parts in all figures.

[page 5]

(Figure 1, 2, 3, 4 and 5)

(Figure 1)

1 total reflection mirror
2 partial reflection mirror

(Figure 2)

(a)
[horizontal axis] frequency

(b)
[upper part] laser oscillation mode
[lower part] frequency

(Figure 3)

2 partial reflection mirror
7 scanning mechanism
11 driving device

(Figure 4)

(a)
[horizontal axis] frequency

(b)
[upper part] laser oscillation mode
[horizontal axis] frequency

(c)
[vertical axis] Fabry-Pérot interferometer
[horizontal axis] frequency

(d)
[vertical axis] Fabry-Pérot interferometer
[horizontal axis] frequency

(e)
[upper part] single frequency oscillations
[horizontal axis] frequency

(Figure 5)

1 total reflection mirror
2 partial reflection mirror

[page 6]

(Figure 60

(a)
[horizontal axis] frequency

(b)
[vertical axis] transmittance of sealed-in gas
[horizontal axis] frequency

(c)
[vertical axis] Fabry-Pérot interferometer
[horizontal axis] frequency

(d)
[horizontal axis] frequency

(e)
[upper part] single frequency oscillations
[horizontal axis] frequency